CONSTRAINTS ON THE DEPTH AND VARIABILITY OF THE LUNAR REGOLITH. B. B. Wilcox[1], M.S. Robinson[2], P. G. Lucey[1], P. C. Thomas[3] and B. R. Hawke[1], [1]Hawaii institute of Geophysics and Planetology, University of Hawaii, 2525 Correa Rd, Honolulu HI 96822, [2]Center for Planetary Sciences, Northwestern University, 1850 Campus Drive, Evanston IL 60208 [3]Center for Radiophysics and Space Research, Cornell University, Ithaca NY 14850.

Introduction: The lunar regolith is produced by impacts of all sizes which break surface materials into finer particles. The depth of the regolith is directly related to the number of impacts per unit area over time. Accurate knowledge of regolith depth can help elucidate properties such as impactor flux, and three dimensional mixing of individual lava flows, and can help us better understand the portion of the Moon most accessible to human exploration. There is a common notion that the regolith depth in mare regions is on the order of 5 m [e.g., 1]. We find that the depth of the mare regolith is highly variable and is commonly greater than 25 m.

Previous Work: Several routes have been taken in an attempt to arrive at the depth of the regolith in the mare, including interpretation of small crater morphology [2], and calculations of the volume of ejecta of all craters in an area [3]. These methods were used on Lunar Orbiter (LO) photographs and suggest a regolith depth of <10 m in the mare. However, small crater morphology may not provide a unique result, as the morphologies of craters interpreted to have formed in or on "bedrock" are also formed by impact into weak, friable materials [2]. And though computing the thickness of regolith based on the volume of ejecta of all visible craters also yields a shallow regolith depth (<10 m), this method does not account for those craters that were obliterated by subsequent impacts or are simply not identifiable due to illumination conditions.

Regolith depth has also been estimated by evaluating the diameter of craters that saturate the lunar surface, and assuming regolith depth to be the excavation depth of these craters [4]. When crater counts are done on LO images the mare surface is only found to be saturated with craters 30 m and smaller, giving a regolith depth of 6 m [4]. However, it has been noted that in LO images (relatively high sun angle) the surface does not appear saturated in small craters, but in near terminator images of the same area (low sun angle) "the shoulder-to-shoulder saturation of 100 to 300 m craters is evident" [5]. Building on this observation, we perform a quantitative analysis of low-sun angle images to understand to what depth the regolith has been excavated, and how variable this depth is.

Data: For comparison of observable craters at different illumination conditions we used the near terminator image AS15-98-13347 (inc. ~89°, ~9 m/p) and the higher sun image LO4-163-H1 (inc. ~70°, ~41 m/p) (Figure 1). Both frames are located at approximately 26°N, 58°W. The images were digitally scanned and all detectable craters were digitized using an interactive monitor-cursor program developed for the project. While the difference in resolution between the two images does not allow for a direct quantitative comparison, the difference in the number of observable craters can be seen with the naked eye (Figure 1). As a starting point for evaluating the depth of the regolith, we examined the equilibrium state of the craters in our

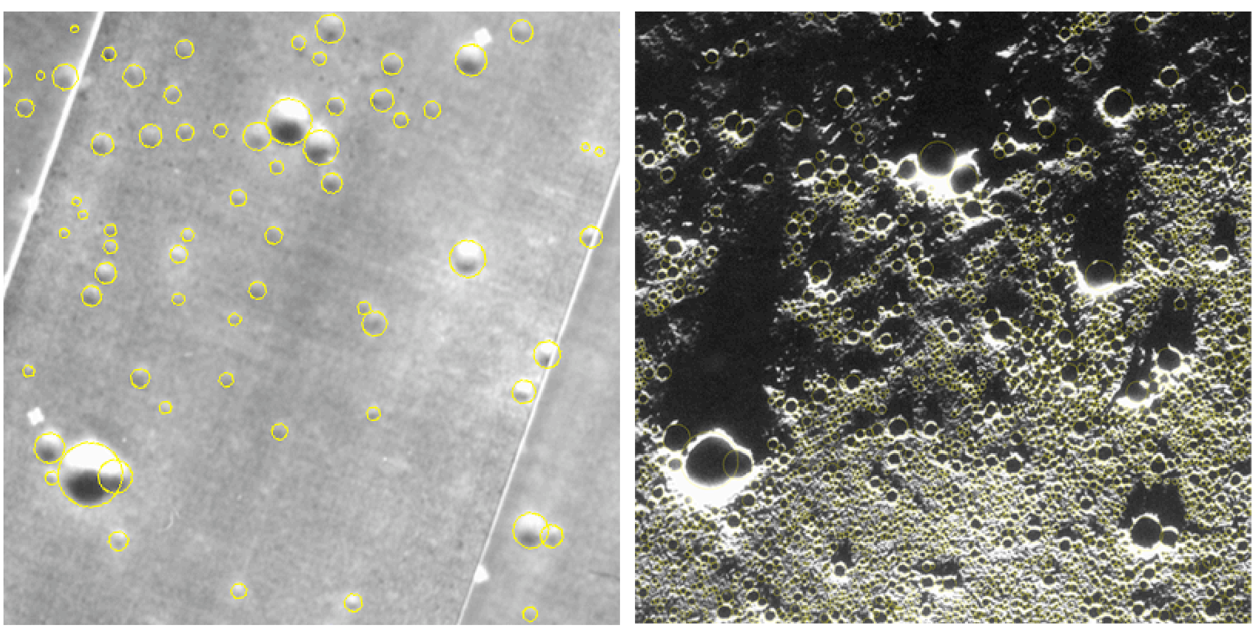

Figure 1. LO image (left) and Apollo 15 image (right) showing the same area under different lighting conditions. Yellow circles indicate craters digitized. Many more craters are visible in the low-sun angle image. Scene is ~16.4 km across.

study area. Equilibrium conditions are achieved when "the crater density becomes so high that each new crater that forms obliterates, on average, one older crater" [6]. For the near-terminator image, an *R*-plot [6,7] shows that that the crater population has reached equilibrium for craters ~230 m in diameter. Craters 230 m and larger, which are responsible for the bulk production of the regolith, cover 24% of the study area, indicating that at least 24% of the surface has been excavated to ~23 m or more (35% of these craters are >230 m in diameter). This is a conservative estimate. Though we excluded much of the shadowed potions of the image, many craters are likely hidden by the shadows of others, and are hard to identify in such a high contrast image. This too does not account for craters that have been destroyed by the generation of craters currently seen.

Conclusions: These findings show that the regolith is perhaps deeper than commonly thought. Instead of ~5 m deep, it is on the order of 25 m deep. These results also show that regolith depth is not constant, and the regolith *cannot* be modeled as a tabular block of loose regolith over a planar bedrock surface. Instead, the regolith thickness is highly variable and depends on the size of craters that have formed in an area. The commonly cited regolith thickness of ~5 m is most likely part of a continuum and represents that portion of the regolith that is most uniformly and finely comminuted and reworked by impactors of the saturation size and smaller. However, a possible apparent contradiction is the preserved stratigraphy observed in Hadley Rille; further work will investigate this.

Future Work: We are also studying the relative Optical Maturity Parameter (OMAT) values for mare craters to further investigate regolith thickness. OMAT values are related to the amount of time the lunar soil has been exposed on the surface [8]. Craters >250 m in diameter were identified and measured in 7 LO images that were controlled and map projected, then located in Clementine images where their OMAT values were calculated. In this preliminary work, we observe the trend of increasing OMAT values (decreasing optical maturity) with increasing crater diameter (Figure 3). That is, as crater diameter and hence depth of excavation increase, the ejecta of these craters is progressively less optically mature. Using high resolution LO images (~1 m/p), the morphology and blockiness of these craters was assessed, and there is no apparent correlation between these characteristics and the OMAT values. Degraded and sharp, blocky and block-free craters are observed along all parts of the slope. This picture is consistent with a deep regolith (≥25 m) where even large craters do not always excavate the optically immature material that would be expected if they had impacted predominantly into bedrock.

References: [1] McKay D. S. *et al.* (1991) in *Lunar Sourcebook*, Cambridge Univ. Press, 285-356. [2] Quaide W. L. and Oberbeck V. R. (1968), *JGR*, *73*, 5247-5270. [3] Oberbeck V. R. and Quaide W. L. (1968), *Icarus*, *9*, 446-465. [4] Gault D. E. (1970), *Radio Sci.*, *5*, 273-291. [5] Soderblom L. A. (1972), *Ap. 15 Prelim. Sci. Rep.*, *NASA SP-289*, 25-87 – 25-91. [6] Melosh H. J. (1989), *Impact Cratering*, Oxford Univ. Press, New York, 245 p. [7] Crater Analysis Techniques Working Group (1979), *Icarus*, *37*, 467-474. [8] Lucey P. G. *et al.* (2000), *JGR*, *105*, 20377-20386.

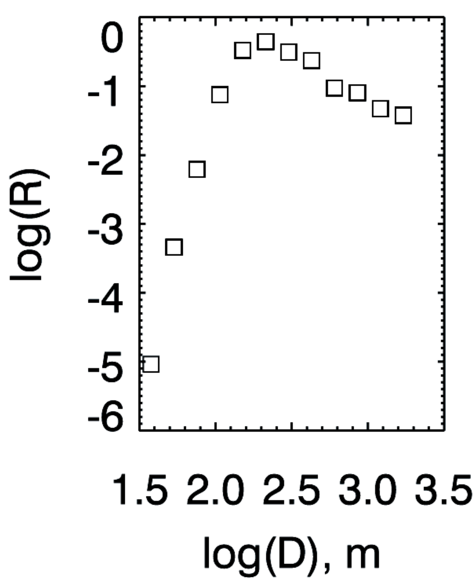

Figure 2. *R*-Plot of craters digitized from image AS15-98-13347. Equilibrium diameter is ~230 m.

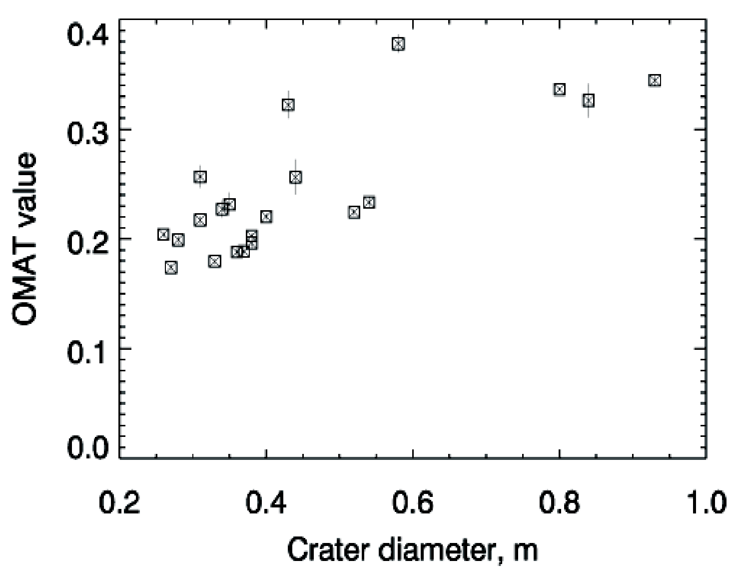

Figure 3. Optical Maturity values versus crater diameter for small mare craters.